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How visual information influences coordination dynamics when following the leader

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HIGHLIGHTS

- We contrasted follow-the-leader coordination with global and local information sources.
- Spatial synchronization was not significantly affected in absence of segmental information.
- Segmental information was found to benefit temporal synchronization.
- Global information can be sufficient, but with increased temporal constraints segmental information becomes more important.

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ABSTRACT

Coordinating one's movements with others is an important aspect of human interactions. Regulating the distance to other moving agents is often necessary to achieve specific task goals such as in invasion sports. This study aimed to examine how distance regulation is mediated by different sources of information that are typically available when humans coordinate their actions to others. Participants followed a virtual leader that moved backwards and forwards, and were instructed to maintain the initial distance. In one condition, participants were presented with a life-size fully animated human avatar as the leader, displaying both segmental (limb motion) and global (optical expansion) motion information. In the other condition, participants had to follow an expanding and receding sphere in which segmental motion information was absent. Optical expansion rates revealed that participants regulated distance equally effective in both conditions. Given the phase relation and response times to direction changes however, the timing to the leader appeared to be more accurate in the avatar condition. These results provide support that forward-backward following can indeed be successfully mediated through global information, but that detection of segmental information allows for earlier tuning to another person's movement intentions.

A fundamental part of our existence and daily lives entails interacting with others. Indeed, increasing interest in inter-agent coordination has seen numerous attempts to understand coordinated performances in nature [1] and more specifically amongst humans [2]. While coordinating movements with others, agents (have to) adapt to (changes in) behaviour of other agents and also to the surrounding environment. In many situations the inter-agent coupling yields synchronization tendencies [3], which often does not require any conscious effort, as for example with crowds clapping in unison, walking side-by-side, or when sitting in a rocking chair [4–6]. Although in specific cases agents are physically coupled [7,8], in most situations inter-agent coupling is mediated through (predominantly visual) perceptual information [e.g., 9]. Some information sources may allow for stronger coupling than others and susceptibility to different sources may vary [9]. However, trying to identify such information sources while maintaining representative experimental designs can be challenging [10].

Regulating the distance to other moving agents is a prevalent part of such interactive coordination and is important for various purposes, for example in social context [11], or simply during transport, where distance is regulated to avoid collision [12]. Inter-agent distance is also of particular importance in one-versus-one subphases in a large variety of sports (e.g., basketball, boxing, or rugby [13–15]). Ducourant and colleagues [16] examined distance regulation using a "follow-the-leader" task where two people walked forwards and backwards while facing each other, to analyse the

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effect of initial inter-agent distance upon dyadic coordination. In their task, the follower aimed to maintain constant inter-agent distance. Although they found that the followers' step characteristics (e.g., length, velocity, frequency) were different from the leaders' step characteristics, the followers were able to stably maintain the initial inter-agent distance. The authors therefore surmised that the coupling took place on a more 'global' level, rather than the follower trying to directly mimic the leader's steps. An interesting question arises from this work in terms of what information is used to regulate inter-agent coordination. In the present study we further investigate the suggestion of global coupling by contrasting 'global and local' sources of visual information for a similar follow-the-leader task.

In theory, a follower could mirror the leader's movements precisely (both in time and space). However, as a follower needs time to respond to a leader, spatiotemporal variances are introduced. To compensate for such 'errors', this would imply more or less anticipatory coupling based on salient information sources. Pertinently, in such a task, some form of visual information is used to regulate inter-agent distance. A potential source could be *global* motion information, for example the change in optical size of an object or agent can inform an observer about positional changes [17]. Indeed, many studies have shown how (detecting) changes in optical size – which is directly related to distance – is of importance for interception, collision avoidance and distance regulation in general [17–20]. Alternatively, *segmental* motion information could be used. This refers to how the body parts (e.g., limbs) of the observed agent move in relation to each other (cf., local or relative motion information [21]). Segmental motion information could provide important temporal information about the gait-cycle which could be used to anticipate upcoming actions. That is, changes in direction imply altered inter-segmental patterns to decelerate the CoM, for instance by slightly tilting the trunk and placing the stance leg a little further than in previous steps. In similar vein, the preparatory movements of a tennis server can provide anticipatory information about the serve direction [22]. In this regard, studies using point-light displays (i.e., using light-emitting diodes placed upon the limbs) highlight how segmental information alone can reveal numerous characteristics of a person's actions and intentions [23].

The aim of the present study is to examine how such global and local information sources affect coordination in a follow-the-leader task. The theoretical approach we adopt extends from recent studies that have adopted a dynamical systems approach to successfully describe coordination between persons [13,24] and also between groups [25]. In our study participants had to maintain a constant distance from a 'leader' that appeared in two different forms (see Fig. 1). In the first condition, a life-size, animated avatar presented segmental information as well as changes in optical size. In the second condition an expanding and receding animated sphere (similar in absolute size to the avatar) provided solely changes in optical size as an indication of its relative displacement. The movements of both the avatar and sphere were animated based on a previously recorded human, thus typical acceleration and deceleration patterns of gait prior to direction changes were the same in both conditions.

Because global information can specify action in a variety of *discrete* coordination tasks [14,18,26], we hypothesized that in this cyclical coordination task the optical expansion rates would not differ between the two conditions. At the same time, we expected that as segmental motion information may allow for earlier anticipation, this would lead to tightening of the temporal synchrony in the avatar condition. We explored these predictions by measuring the degree to which the follower nulled the optical expansion (i.e., maintained a constant distance: spatial synchronization), the point-estimate relative phase and the response times at each direction change (temporal synchronization).

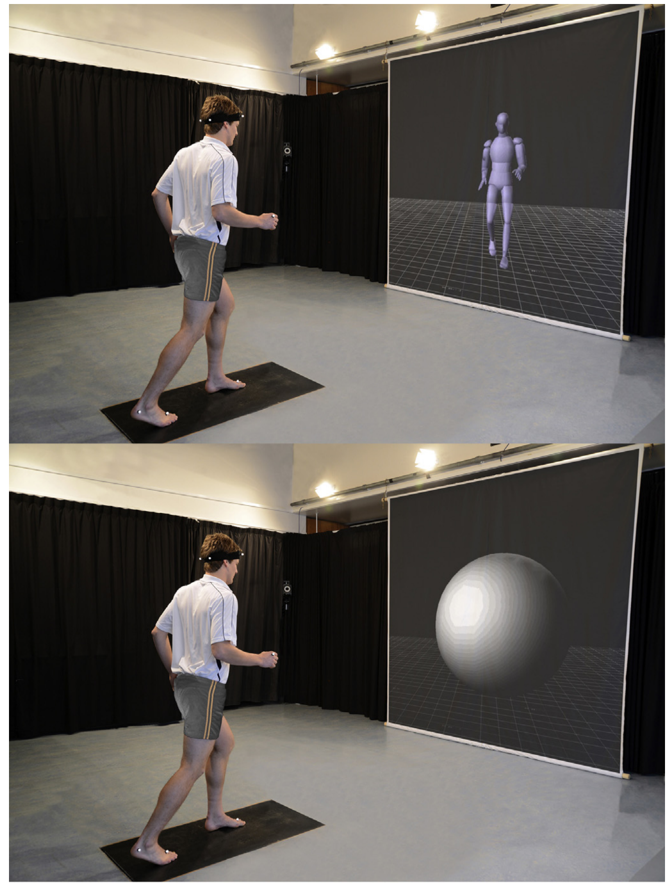

Fig. 1. Experimental setup: Avatar condition (top) and Sphere condition (bottom).

To create the virtual 'leader' animations, the movement trajectories from a real person (age 24, height 1.88 m) walking backward and forward were recorded. A 10 camera Motion Analysis System (Vicon Motion Systems, Inc., Centennial, CO) was used to measure the 3D-gait kinematics of the person at 200 Hz within a measurement volume of 6×2 m. The kinematics were recorded using a 15-segment model, with reflective markers at each joint and on each segment. The trajectories of these markers were used to reconstruct the avatar and sphere videos (Fig. 1) with Autodesk's MotionBuilder (Autodesk Inc., San Rafael, CA, 2013). For the sphere, only the displacement along the sagittal plane – eliminating any vertical and lateral displacement – were used to animate the backward and forward motion. A total of 25 different 'leader' trajectories were generated. The virtual conditions were projected on a large 4×4 m screen with a Panasonic LCD PT-LB20 projector (resolution 1024×768, 2000 Lm). Each experimental trial lasted for 22 s, on average there were 11.18 ± 0.85 direction changes.

Thirty-four healthy males (age $M \pm SD = 28.1 \pm 6$ years) volunteered to participate as 'followers' in the experiment. None of the participants reported motor or sensory impairments. Participants were instructed to follow-the-leader by moving backward if the leader moved forward, and vice versa, and to maintain the initial distance with the leader. No further instructions were given as to how the participant had to follow the leader. Ethical approval was obtained from the participating institution's human ethics committee prior to data collection. In each condition – presented in randomized blocks –, participants were given 3 practice trials before completing 22 trials. The position of the participants' feet was recorded to determine the step characteristics; the position of the head was used to represent the displacement of the whole-body [16]. Anterior–posterior movements were obtained